

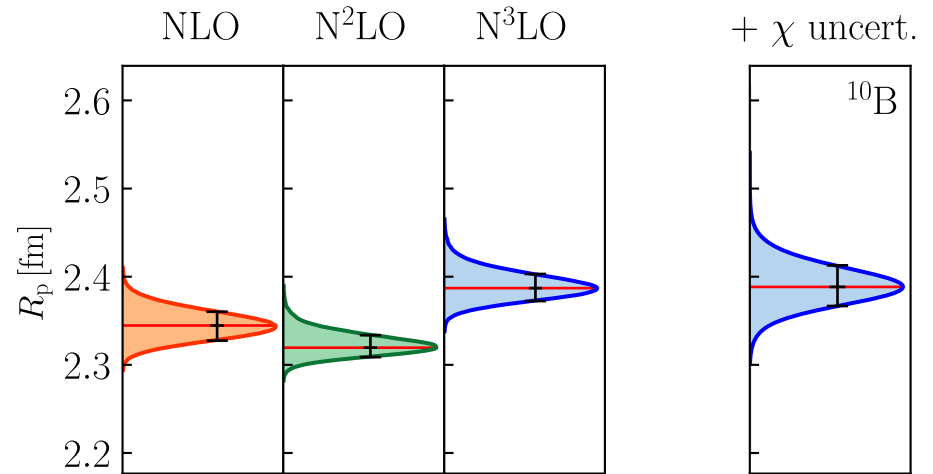
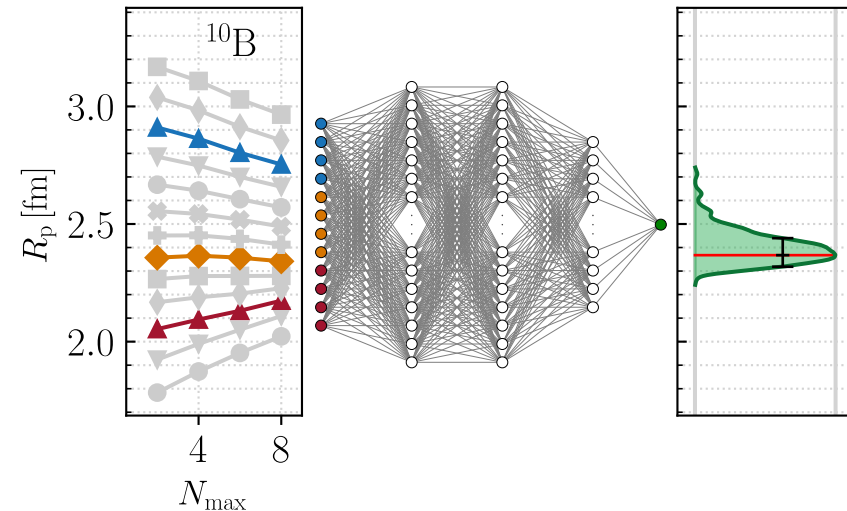
# Precision NCSM Calculations of Nuclear Radii

NCSM  
Calculations

Data  
Evaluation

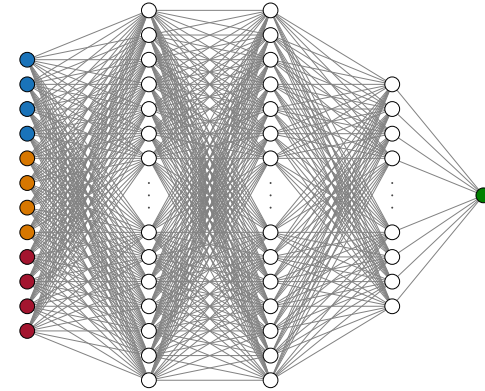
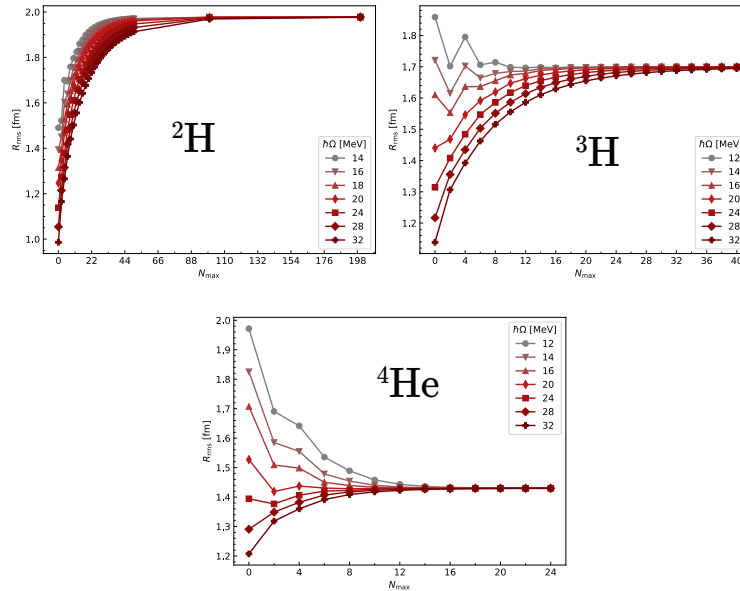
Post-Processing

Final  
Prediction



- Utilizing pattern recognition capability
- Network has to be trained
- Trainings data from converged calculations

Network training



Multiple networks can be constructed and trained

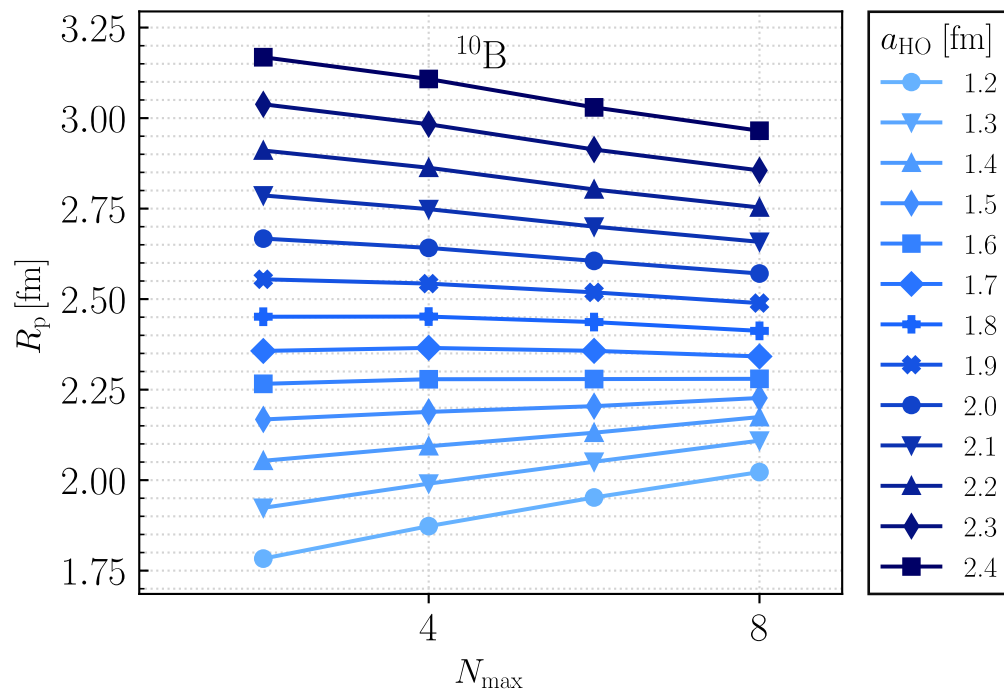
NCSM  
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Prediction

- Range of  $N_{\max}$  and  $a_{\text{HO}}$
- Insufficient convergence
- Extrapolations necessary



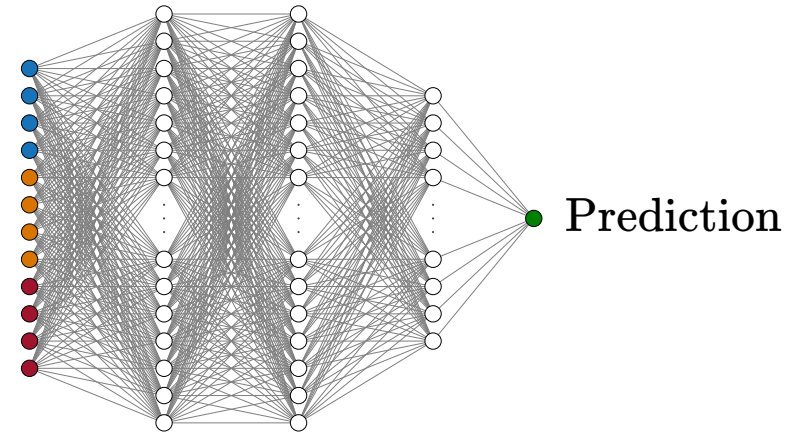
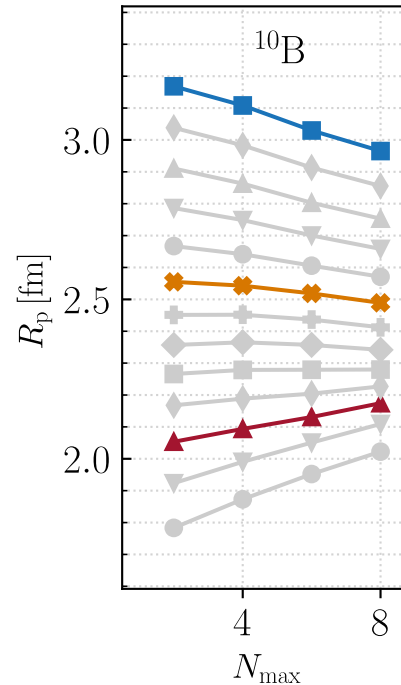
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Prediction

- Samples as input for ANNs
- 3  $a_{\text{HO}}$  at 4 consecutive  $N_{\text{max}}$
- Constructing distribution from ANN predictions



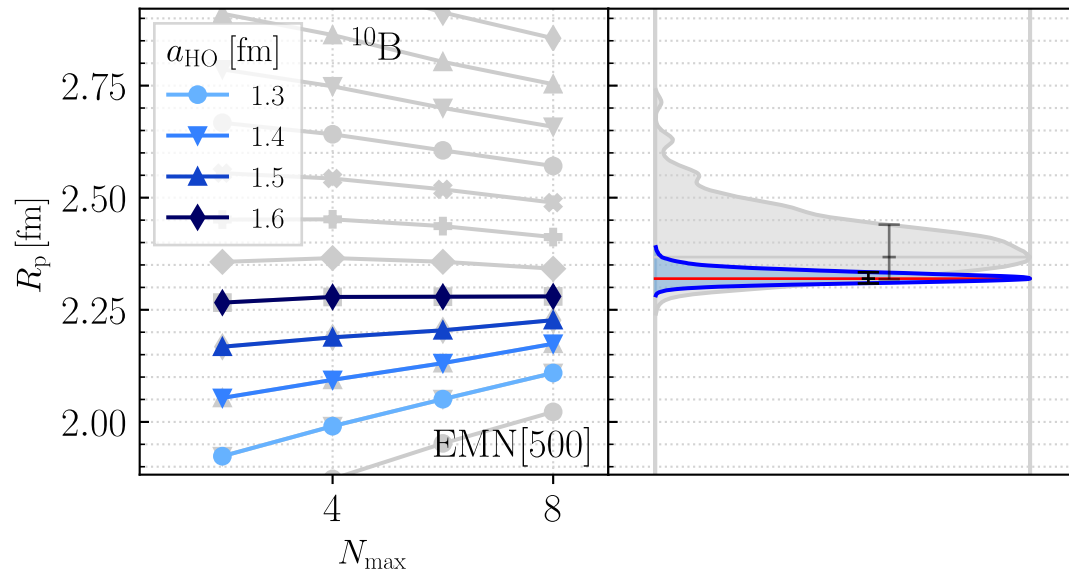
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- Mitigating unwanted artifacts in histogram
- Selecting 4 flattest ascending  $a_{\text{HO}}$  sequences
- Statistical analysis extracts many-body and network uncertainties



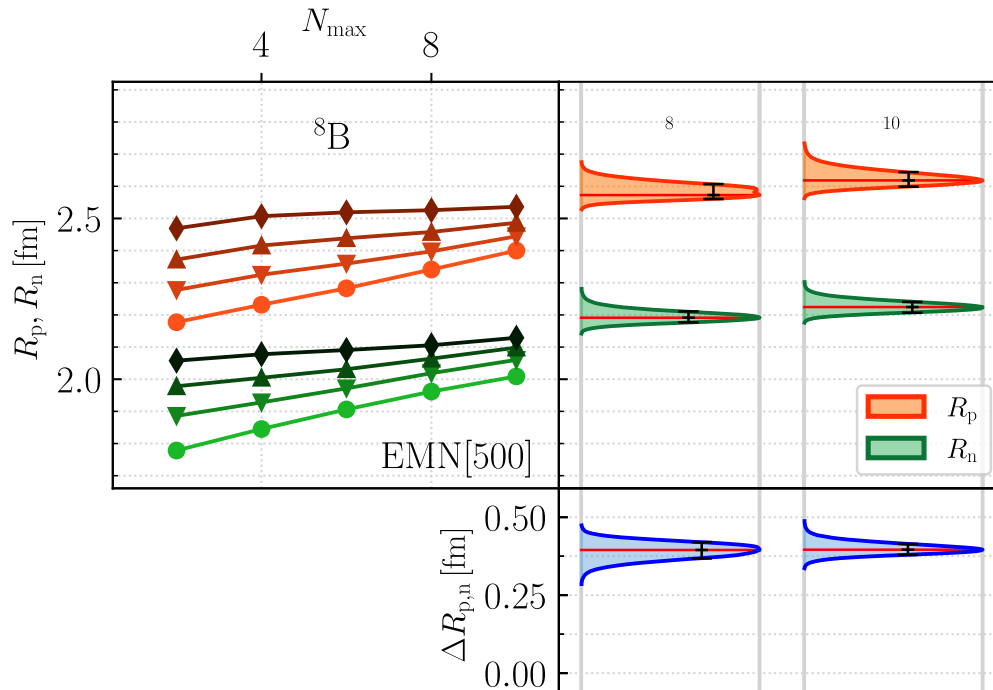
NCSM  
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Prediction

- Sample-wise subtraction of ANN predictions
- New distribution inherently includes correlations
- Errors smaller compared to classical propagation of uncertainty



NCSM  
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Data  
Evaluation

Post-Processing

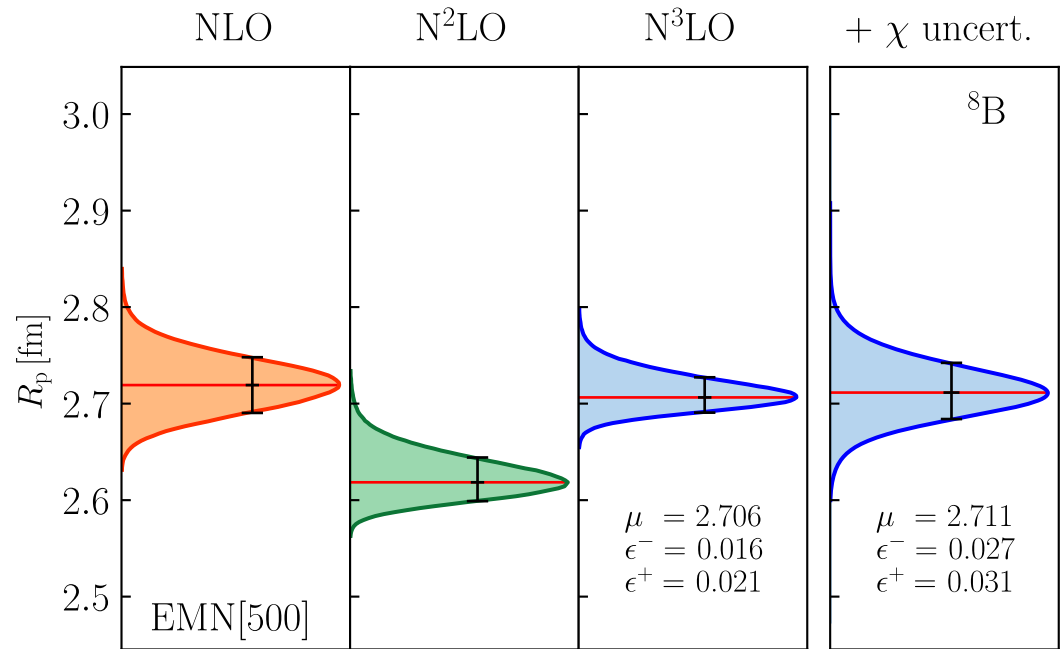
Final  
Prediction

Family			
EMN	NLO	N <sup>2</sup> LO	N <sup>3</sup> LO
SMS	NLO	N <sup>2</sup> LO	N <sup>4</sup> LO+

## BUQEYE

- Estimate effect of missing higher orders
- Select most probable value from each order's histogram
- Combine many-body and interaction uncertainties

J.A. Melendez et al. Phys. Rev. C 100, 044001 (2019)



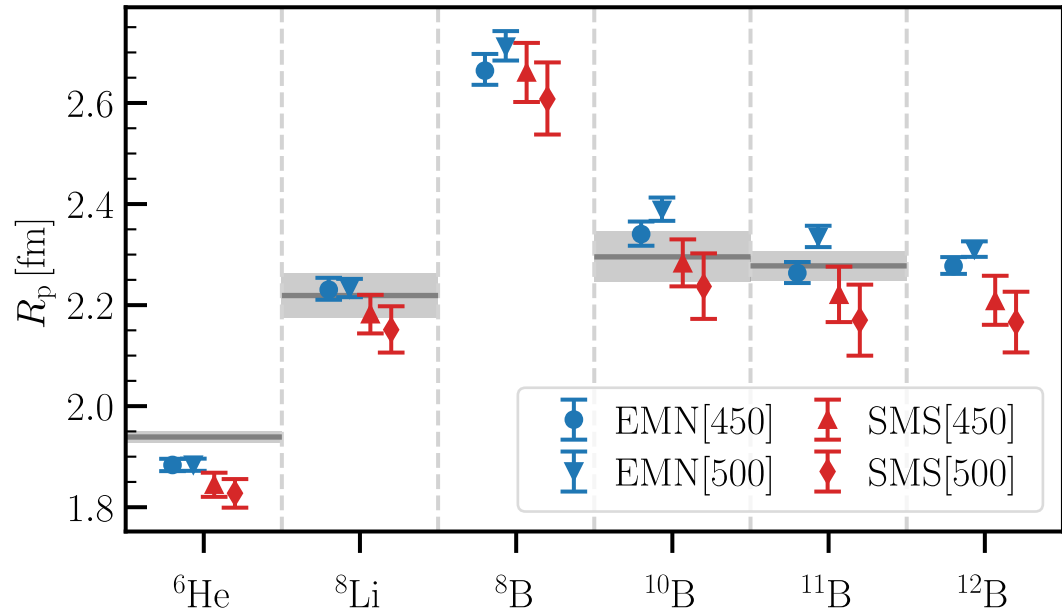
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Prediction

- Predictions including many-body and chiral uncertainties
- Compared to experimental data (if available)
- Compatible results from both interaction families





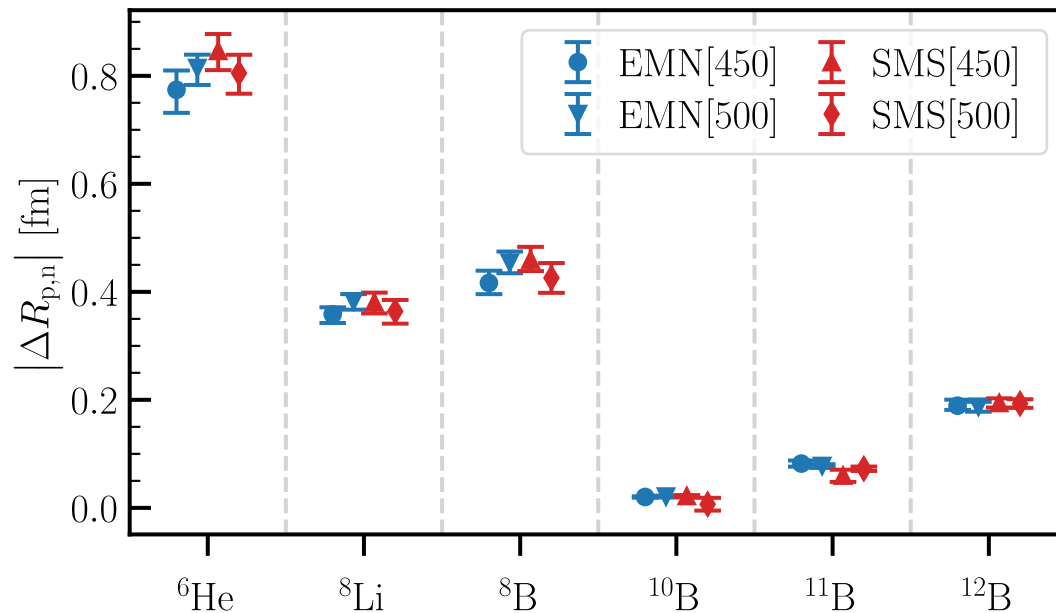
NCSM  
Calculations

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Prediction

- Radius differences in much better agreement across interactions
- Larger proton-neutron radius difference for  ${}^8\text{B}$
- ${}^6\text{He}$  as accepted halo nucleus



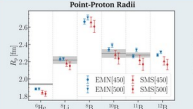
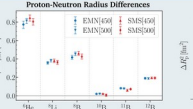
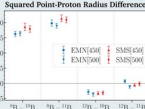
# Precision NCSM Calculations of Charge Radii



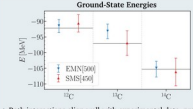
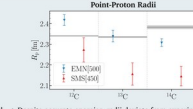
Tobias Gesser, Tobias Wolfgruber, Marco Knoll, Pieter Maris and Robert Roth

Motivation	Workflow
<ul style="list-style-type: none"> <li>Nuclear radii are fundamental observables that provide insights into nuclear structure</li> <li>NCSM commonly used for calculating nuclear observables in light nuclei based on realistic interactions from chiral effective field theory</li> <li>Limited by rapidly growing model spaces, leading to insufficient convergence for shell nuclei</li> <li>Radii require large model spaces due to long-range wavefunction sensitivity</li> <li>Artificial neural networks (ANNs) are used to predict converged values from NCSM data [1, 2]</li> <li>The neutron-deficient nucleus <math>{}^8\text{B}</math> is of special interest as a potential proton halo candidate [3, 4]</li> </ul>	<p><b>Data Evaluation</b></p> <ul style="list-style-type: none"> <li>Samples are constructed with 3-<math>n_{\text{np}}</math> at 4 consecutive <math>N_{\text{max}}</math> from NCSM data</li> <li>Constructing distribution from predictions for all possible samples</li> <li>Pre-selecting 4 flattest ascending <math>n_{\text{np}}</math> sequences to mitigate artifacts</li> </ul> <p><b>Calculating Radii Differences</b></p> <ul style="list-style-type: none"> <li>Sample-wise subtraction of ANN predictions to obtain difference observables</li> </ul> <p><b>Interaction Uncertainties</b></p> <ul style="list-style-type: none"> <li>NCSM calculations performed for multiple chiral orders</li> <li>Intrinsic effect of mixing higher orders via Bayesian analysis</li> </ul> <p><b>Post Processing</b></p> <ul style="list-style-type: none"> <li>Student <math>t</math> distribution obtained from SUQEYE point-wise model [5]</li> <li>Convolved with ANN predictions, now including many-body and interaction uncertainties for highest order</li> </ul>

### Boron Isotopes


Point-Proton Radii	Proton-Neutron Radius Differences	Squared Point-Proton Radius Differences
		
<ul style="list-style-type: none"> <li>Results for all four interactions at highest order compared to experimental data taken from Refs. [6, 7] for full uncertainty quantification</li> <li>Both interaction families give comparable results, though SMS tends to smaller radii predictions</li> <li>Good agreement to experiments, except for <math>{}^8\text{Be}</math>, where the radius underestimated</li> </ul>	<ul style="list-style-type: none"> <li>Radius differences in much better agreement across interactions with significantly smaller uncertainties</li> <li>Larger proton-neutron radius difference for <math>{}^8\text{B}</math> compared to other boron isotopes</li> <li>Not as pronounced as for accepted halo nucleus <math>{}^8\text{He}</math></li> <li>Potentially extended proton density distribution for <math>{}^8\text{B}</math> and neutron density distribution for its mirror nucleus <math>{}^8\text{Li}</math></li> </ul>	<ul style="list-style-type: none"> <li>Experimentally accessible via isotope shift [3]</li> <li>Suitable for comparing results and independent from the proton charge radius</li> <li>With <math>{}^7\text{B}</math> and <math>{}^{11}\text{B}</math> as reference nuclei, <math>{}^8\text{B}</math> shows an increased radius</li> <li>Results are largely consistent across interactions</li> <li>Prediction for <math>{}^7\text{B}</math> smaller radius compared to <math>{}^8\text{B}</math>, but no difference compared to <math>{}^9\text{B}</math></li> </ul>

### Carbon Isotopes

Ground-State Energies	Point-Proton Radii	Conclusion & Outlook
		<ul style="list-style-type: none"> <li>Increased precision for ANN extrapolations of NCSM calculations for radii</li> <li>Reduction of interaction dependencies by calculating radius differences</li> <li>Combined many-body and interaction uncertainties</li> <li>Prediction of extended proton (neutron) density distribution for <math>{}^8\text{B}</math> (<math>{}^8\text{Li}</math>)</li> </ul> <p><b>In the Future</b></p> <ul style="list-style-type: none"> <li>Comparing predictions with upcoming high precision laser spectroscopy for boron and carbon isotopes</li> </ul>
<ul style="list-style-type: none"> <li>Both interactions align well with experimental data, providing a good description of energies within uncertainties</li> <li>Despite accurate energies, radii deviate from experiments</li> <li>SMS systematically underpredicts radii</li> </ul>		

Technische Universität Darmstadt, Germany

References: [1] M. Knoll, T. Wolfgruber, et al., Phys. Lett. B 808, 137701 (2021); [2] T. Wolfgruber, M. Knoll, and R. Roth, Phys. Rev. C 100, 044207 (2019); [3] B. Meck, J. Holties, et al., Phys. Rev. Lett. 102, 092501 (2009); [4] B. Meck, J. Holties, et al., Phys. Rev. Lett. 102, 092501 (2009); [5] J. A. Moro, et al., Phys. Rev. C 84, 044201 (2011); [6] M. Wang, W. J. Huang, et al., Chin. Phys. C 45, 030001 (2012); [7] S. Aupiais, et al., Phys. Rev. Lett. 106, 092501 (2011)



# Thank you for your attention!

## Find more details on my poster

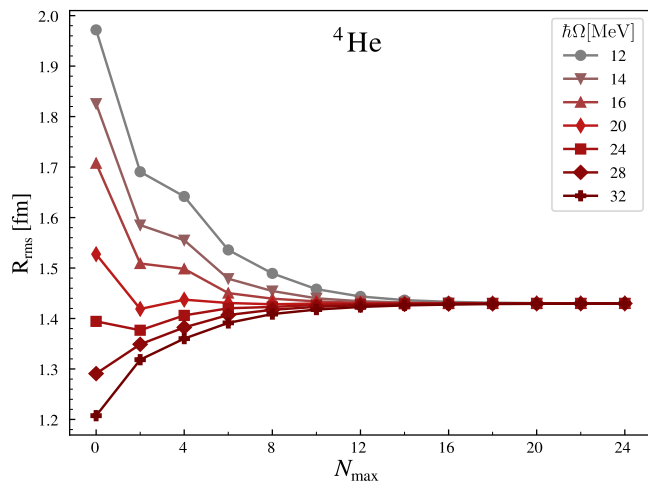
NCSM  
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Convergence reached  
for few-body systems



Interactions derived  
from chiral EFT

- non-local (EMN)
- semi-local (SMS)

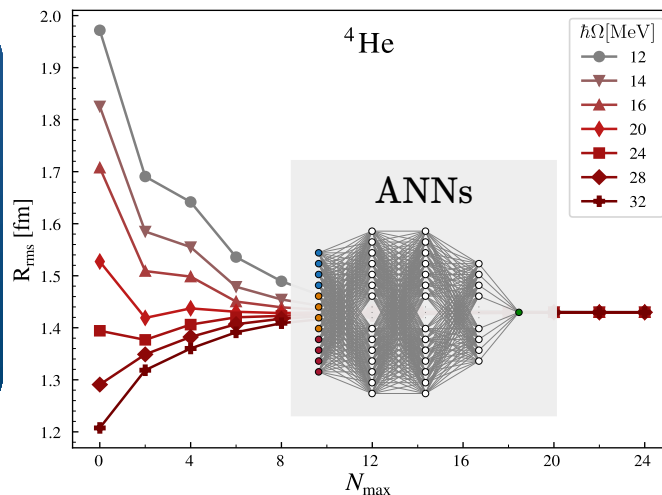
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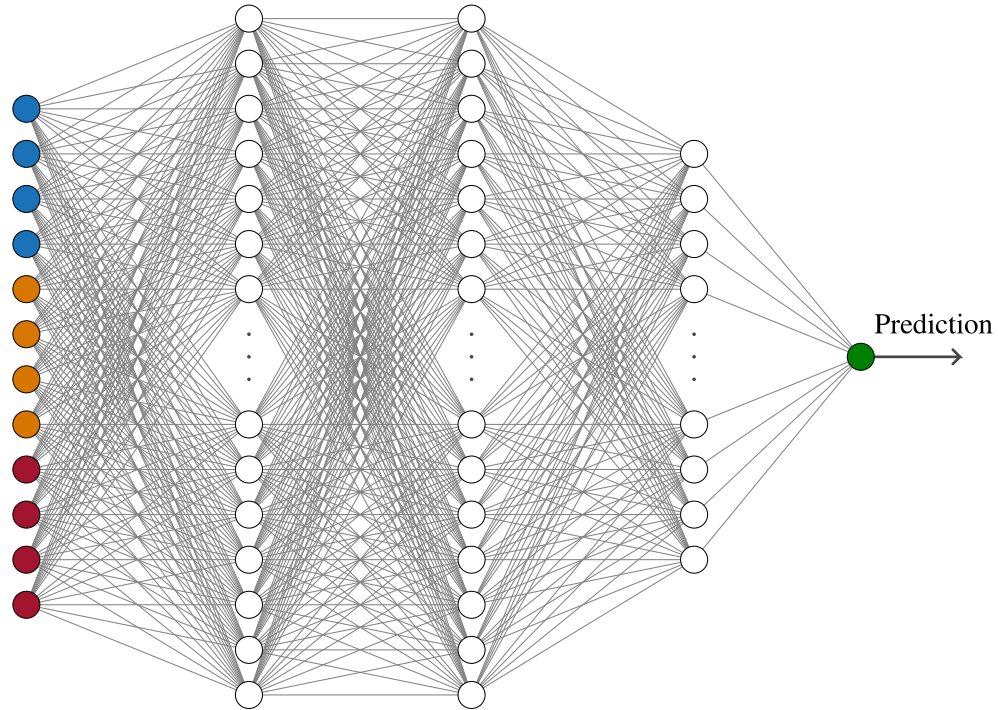
- For different oscillator frequencies or lengths
- Convergence reached for few-body systems



Interactions derived  
from chiral EFT

- non-local (EMN)
- semi-local (SMS)

Extrapolations necessary  
for heavier nuclei

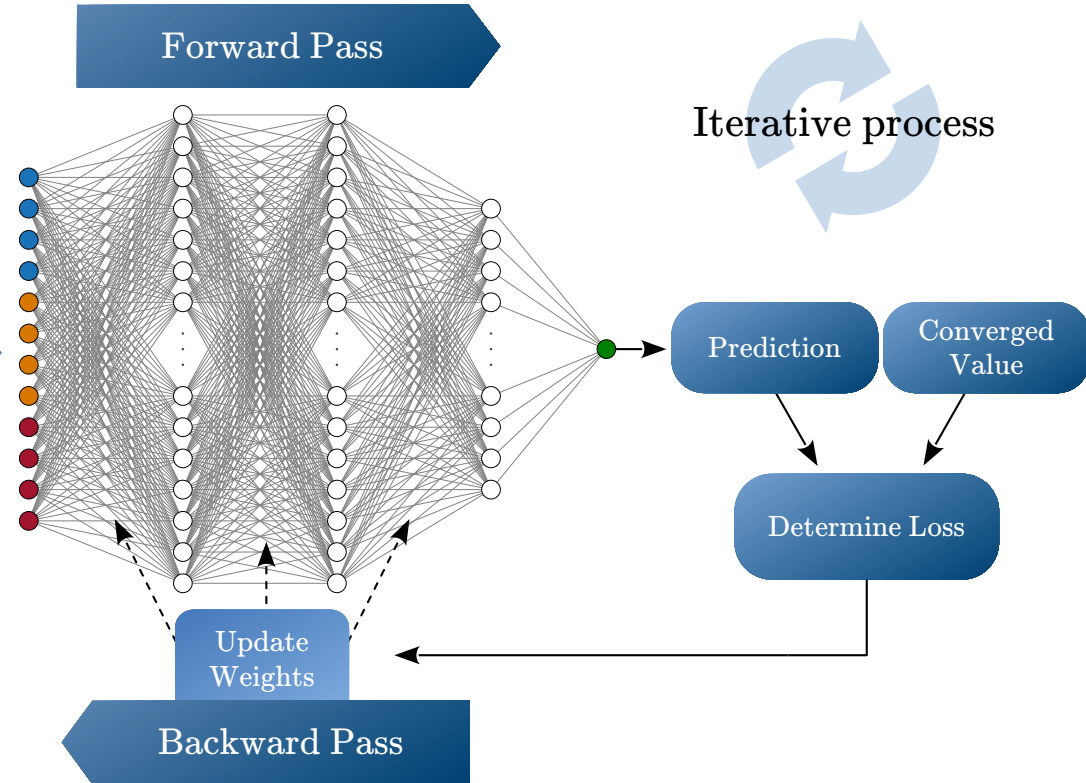


Wolfgruber, T et al., arXiv:2310.05256, 2023

- Dense feed forward network

Requires training to capture convergence behavior

- Multiple networks for multiple predictions



- M. Knöll et al., Phys. Lett. B 839, 2023.
- T. Wolfgruber et al., arXiv:2310.05256, 2023
- B. Maaß et al., Phys. Rev. Lett. 122, 2019.
- W.G. Jiang et al., Phys. Rev. C 100, Nov. 2019.
- P. Maris et al., Front. Phys. 11, Apr. 2023.